Impact of the auroral ionosphere on HF radio propagation

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1. Introduction

Quality of the HF communications at the high latitudes depends on a state of the ionosphere and radio wave propagation conditions. Absorption (auroral and polar cap) of HF signal power, the anomalous ionization in the ionospheric F-region (F2S) at night-hours of winter and equinox, significant negative disturbances in the F2-layer at day-time of all seasons, effect of the non-great-circle propagation, formation of some sporadic Es-layers of different types, increased diffusion of signals reflected from the ionosphere and signal distortions caused by rapid and deep fadings often take place here [1-4].

At winter time when the high-latitude ionosphere is brightened by the Sun very little, the main ionospheric trough (MIT) and sporadic formations in the largest measure impact on radio communication inside the auroral zone (Φ_L = 60 - 70^0). A value of this influence depends on a level of the ionospheric disturbance stipulated by certain geomagnetic activity. Under the quiet magnetic conditions (planetary index K_P = 0 - 1) at evening and night-hours when the auroral ionization and the ionization caused by solar ultraviolet radiation are small, the MIT can spread all over the auroral zone. At that time the most difficult conditions are created for passing the signals through HF radio channels located in this zone. On the poleward edge of the trough (PET) coincided with the equatorward edge of the auroral ionization zone and to the north of it the electron concentration sharply increases both in the F- and the E-regions of the ionosphere. Appearance of sporadic Es-layers of different types and anomalous ionization in the F-region are shown often here. Consequently the radio wave propagation conditions will be determined both the MIT itself and its poleward edge.

The aims of the present study are (1) to determine the extent to which the quality of transmitted information through the real HF links located inside the auroral zone (Φ_L = 64 - 66^0) is affected by the MIT, the sporadic Es-layers, the F2S regions and the auroral absorption; (2) to reveal how to select the optimal operating frequencies correctly on these links for increasing the communication quality under the most difficult conditions of signal broadcasting. The mentioned tasks will be considered basically on the materials of long complex experiments.

2. Experiment description

Two HF radio paths working simultaneously are the real communication links. They are disposed in the auroral zone and have common receiving center on the latitude of Murmansk, Φ_L = 65.2^0. The first path is 1420 km long and passes along the auroral oval. The second one is 510 km long and located across the auroral oval to the north of the receiving center. Operating frequencies on the radio paths are being selected within the following bands: for the first one $f_1 = 9 \pm 1$ MHz and for the second one $f_2 = 6 \pm 0.5$ MHz. A running frequency of any path are selected arbitrary from the range, reasoning by absence of the radio-station interference on this frequency. The observation period is the last but one minimum of solar activity.

For estimation of a geophysical situation, the data of the ionosonde, the magnetometer and the riometer which all are located nearly the receiving center were used. The disturbed conditions of the radio link operation correspond to K ≥ 3 (30% of the observation time) and the quiet ones - K < 3 where K is the three-hour index of magnetic activity. During quiet period, the receiving center is located in the area of the MIT. An ionization level in the ionosphere is low here therefore any reflection patterns on the ionosonde ionograms are absent. During moderate disturbances the diffusional electron precipitation edge considered as the PET is located to the south of the receiving center. The reflection patterns from the sporadic layers in the E- and the F-regions of the ionosphere arise on the ionograms. For the strong disturbances when an absorption level by the riometer is significant, getting and analysis of the ionograms are difficult.

3. Results of observations

Let's consider the effects of the MIT. The average positions of the PET in coordinates invariant latitude-local time for two levels of geomagnetic activity are shown in Fig. 1. The curves 1 and 2 are the results of statistical analysis of signals passing on the radio paths as well as of ionosonde data for the winter months of the solar activity minimum

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[5]. The curve 1 corresponds to quiet conditions ($\Sigma K < 15$), and the curve 2 does to disturbed ones ($\Sigma K \geq 25$). From this figure we notice that the PET moves above the reflection points of the paths located on the latitude $\Phi_L \approx 65^0$ twice for twenty-four hours. Under quiet conditions these moments are 22.30LT and 07.00LT, for disturbed conditions: 18.00LT and 07.30LT. The mentioned moments are presented in Fig. 2c and Fig. 2g by black rectangles.

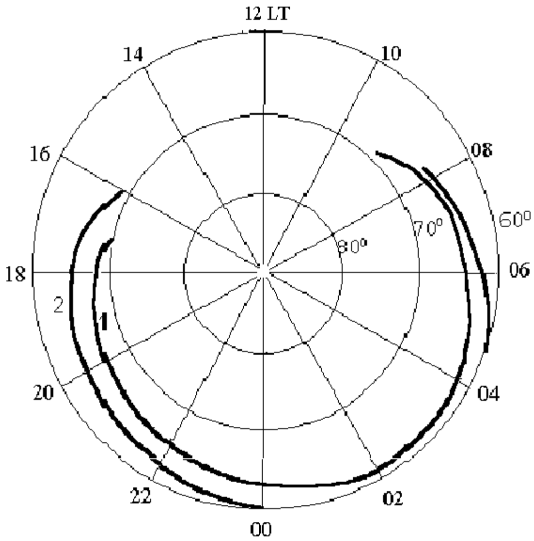

Fig. 1. Positions of the PET for winter months of the solar activity minimum: 1- quiet conditions; 2 - disturbed ones.

Fig. 2 illustrates the observation results for quiet conditions, K < 3 (panels a, b ,c, d), and for the disturbed ones, K ≥ 3 (panels e, f, g, h). Referring to Fig. 2a and Fig. 2e, we have the following patterns: averaged through different days of winter period values of MUF-F2 and MUF-Es calculated by the ionosonde data and average operating frequency "f" from the band of the path located along the auroral oval, D = 1420 km. Fig. 2b and Fig. 2f illustrate the same but for the path located across the auroral oval, D = 510 km. Examination of the curves in Fig. 2a,b and Fig. 2e,f leads us to the following conclusion. In winter when the high-latitude radio paths are affected by the MIT within periods: 17.00LT - 22.00LT and 07.00LT - 09.00LT for K < 3 and accordingly 16.00LT - 18.00LT and 08.00LT - 10.00LT for K ≥ 3, signals passing through the paths are appreciably worse. The maximum useable frequencies do not exceed values 2 - 3 MHz. A signal strength at receiving center obliged basically to the scatter effects is very small. Therefore the HF communication will be not reliable under these conditions.

The moments of passing the PET above two auroral paths move to earlier evening hours and later morning ones with increasing the geomagnetic activity. Thus if the sporadic ionizations in the E- and the F-regions concerning to the PET during a quiet period are shown at night from 22.00LT to 07.00LT, so during a disturbed period - from 17.00LT to 09.00LT.

It should be noted that the patterns in Fig. 2a, 2b and Fig. 2e, 2f have got the qualitatively equal character. By this is meant that the impact of geophysical factors on radio signals traversing the auroral oval is more significant than the impact of a path orientation and its length.

Fig. 2c and Fig. 2g present daily variations of average probability of passing the signals on two considered paths simultaneously under quiet and disturbed conditions accordingly. Construction of the graphs was fulfilled on the data of round-the-clock operation of communication links within five years in winter period. By convention the probability of passing the signals at a considered moment P(t) = 1 when on receiver inputs the ratio signal/noise is no less than 1 simultaneously on two radio links; P(t) = 0.5 when the ratio signal/noise is more or equal to 1 if only for either of two paths; P(t) = 0 when the ratio signal/noise is less than 1 for two paths at a time. The data of Fig. 2c confirm the impact of the trough on radio communication is more significant in winter during quiet geomagnetic periods from 17.00LT to 22.00LT and from 07.00LT to 09.00LT. When passing the PET above the reflection points of radio paths both in the evening and in the morning there is a growth of the probability of passing signals at the expense of increasing the PET ionization. The PET changes the structure of reflected waves, prompting sharp growth of the average signal level at the receiving center till several times [6]. Under disturbed conditions (Fig. 2g) the MIT and the PET impact on the radio communication to a lesser degree because there are predominant effects of absorption and sporadic formations there.

Radio wave absorption presented here is the auroral absorption (AA) caused by the electron injection (E ~ 10 - 40 eV) from the plasma sheet. Fig. 2d and Fig. 2h demonstrate probabilities of the AA appearance by the riometer data (f = 32 MHz) for winter months of the solar activity minimum years under quiet and disturbed conditions. The

probability of the AA appearance was being determined as the ratio of a number of the AA events with values exceeding 0.5 dB to a number of all observations. The comparison of the curves "c" and "d" in Fig. 2, and then "g" and "h" in Fig. 2 shows that the auroral absorption significantly impacts on the quality of the information transmission. Absorption growth leads to decreasing the probability of the HF communication. This effect is most pronounced during disturbed periods: the curves "g" and "h" in Fig. 2 are practically anti-correlative.

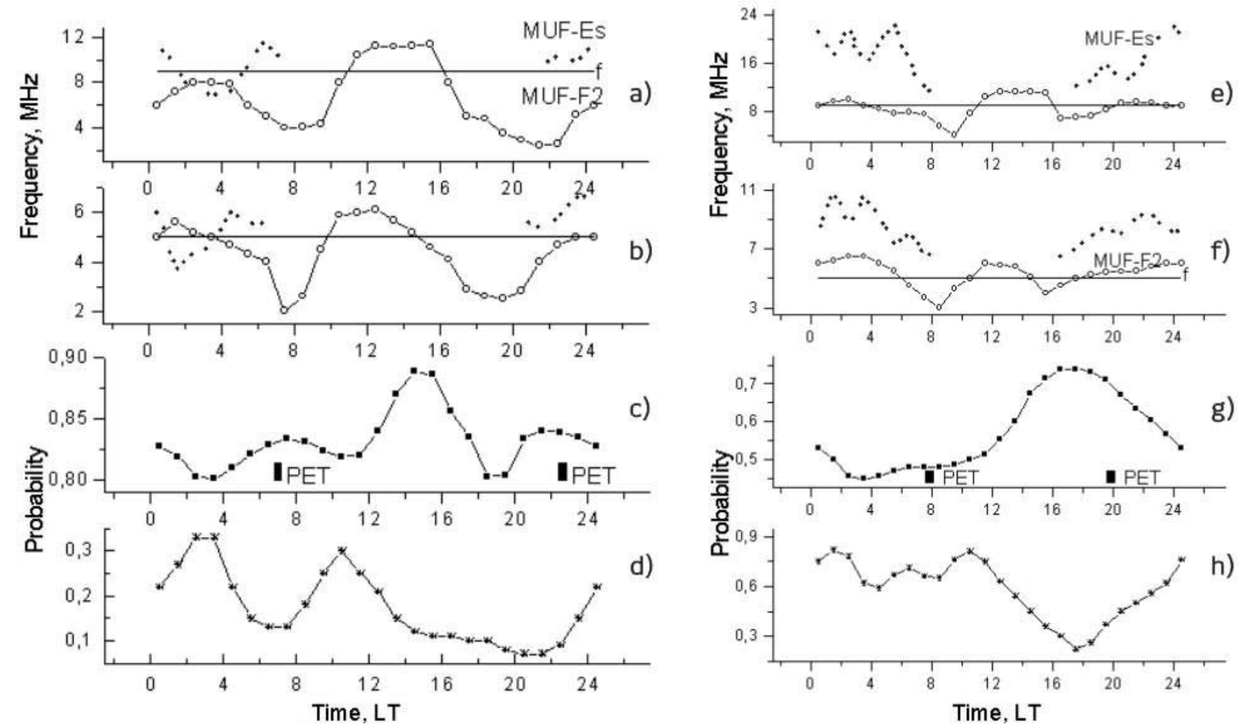

Fig. 2. Averaged diurnal variations of the following parameters: MUF-F2 and MUF-Es - maximum useable frequencies, f - operating frequency for the radio path of length D =1420 km located along the auroral oval: a) averaged under the quiet conditions e) under the disturbed ones; The same parameters for the radio path of length D = 510 km located across the oval: b) under the quiet conditions, f) under the disturbed ones; Probability (reliability) of the HF communication on the paths: c) under the quiet conditions g) under the disturbed ones; Probability of auroral absorption d) under the quiet conditions h) under the disturbed ones.

Let us also consider the role of the F2S formations. Anomalous or sporadic ionization in the ionospheric F-region (F2S) is observed at the winter night-hours as a "thick" layer with some geometrical parameters similar to regular F2 layer but with the critical frequencies exceeding these ones of the normal F2 layer [5]. The equatorward edge of this ionization in the night coincides with the PET and depends of geomagnetic activity. According to our experiment at the invariant latitude $\Phi_L = 65^0$ where the reflection points of radio paths are located, the sporadic ionization F2S appears only during disturbed periods while during quiet periods it is located northward. It could be seen from comparison Fig. 2a and Fig. 2e with Fig. 2b and Fig. 2f accordingly. Namely, at the night time from 19.00LT to 06.00LT the values MUF-F2 (positions "e", "f") on the paths exceed the values MUF-F2 (positions "a", "b") by 1-2 MHz. Therefore the time period Δt, when the average operating frequency f $\leq$ MUF-F2, will be $\Delta t = 5$ for Fig. 2a and $\Delta t = 4$ hours for Fig. 2b as well as $\Delta t = 8$ hours for Fig. 2e and $\Delta t = 12$ hours for Fig. 2f. By doing so, the sporadic ionization F2S under disturbed conditions should contribute to growth of the HF communication reliability however the effect of radio wave absorption at this time plays an important part and it disguises a role of the F2S ionization.

As for the effects of the sporadic Es-layers, Fig. 2a,b and Fig. 2e,f illustrate the variations of the MUF-Es (by dotted line) which are maximum frequencies reflected from sporadic Es-layers for the paths located along and across the auroral zone. One can see that a growth of geomagnetic activity causes increasing the total time of the sporadic Es appearance and rising the MUF-Es values. Therefore it is significant to use the properties of sporadic Es-layers to reflect radio waves for growing the HF communication reliability on the auroral links. However, not all Es-layers could be used successfully for the radio communication aims.

3. Conclusions

The special features of passing the radio signals on high-latitude HF paths located inside the auroral zone by the data of complex experiments are considered. These peculiarities are stipulated by the following geophysical factors: the main ionospheric trough, the poleward edge of the trough, sporadic formations in the ionospheric E- and F-regions, auroral absorption, strength of geomagnetic activity.

Studying the character of radio wave propagation is fulfilled for the worst conditions, which are the dark hours of winters of the minimum solar activity. Mentioned conditions are the worst from the viewpoint of the reliability (probability) of the HF communication. They are determined by statistical materials accumulated on the real HF links in the auroral zone for a period of long standing. According to experiments, it has been found as follows:

- When the radio paths are in the immediate region of the MIT (17.00LT - 22.00LT and 07.00LT - 09.00LT for $K < 3$; 16.00LT - 18.00LT and 08.00LT - 16.00LT for $K \geq 3$), passing the signals through radio channels becomes bad particularly at the premidnight hours. Here the signal amplitudes are small because of radio wave scattering. Therefore the reliability of the HF communication is low within this period. For its growing it is necessary to decrease the operating frequencies till 2-3 MHz.
- When the reflection points of the paths are influenced by the PET (22.30LT, 07.00LT for $K < 3$; 18.00LT, 07.30LT for $K \geq 3$), signal amplitudes at the receiving center become significant. The reliability of the HF communication grows. Operating frequencies on the paths are being chosen within $f = 6\text{-}9$ MHz.
- The anomalous ionization F2S, acting on the radio paths under disturbed conditions of the night hours of winter, must rise the reliability of communication. But significant absorption during this time in reality decreases it.
- For a moderate geomagnetic activity the sporadic ionization in the ionospheric E-region, particularly the E_{sr} layers, at the evening and night hours of winter allows to increase the reliability of the HF communication by selection of higher operating frequencies on the paths till $f = 12\text{-}20$ MHz. The paths must not have lengths more that 2000km.
- A significant level of auroral absorption decreases the reliability of the HF communication inside the auroral zone. However for weak and moderate geomagnetic activity when the auroral absorption is small there are the favorable conditions for passing of the signals on the radio paths and the reliability of communication grows.
- A geomagnetic activity in the auroral zone has three degrees of the impact on the reliability of communication. When it is absent (quiet conditions) the reliability of communication is low because of influence of the MIT. For weak and moderate geomagnetic activity the reliability is high. For strong geomagnetic activity the reliability of communication is low again because of the auroral absorption.
- The quality of the HF communication in the auroral zone basically depends from some geophysical factors like the MIT, the PET, sporadic E_s and F2S, absorption but not from the path parameters.

The obtained results concerning the probability estimations of passing the signals on the one-hope auroral radio paths should be taken into account for prediction of the HF radio communication and for planning the polar links operation.

4. References

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